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Factory planning system considering energy-efficient process under cloud manufacturing

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Abstract

Cloud computing sets to make a change in business between enterprises over the internet based on services providing dynamically reconfigurable and virtualized networks. It is difficult for an aircraft manufacturer to consider the performance and status of each factory (i.e., capacity, inventory, order, technology, etc.) because of the huge amount of suppliers. In legacy environments, the supplier consumed a long time to identify the machine and process required and the energy to be consumed in order to satisfy a new customer demand. If the process occurred with a new order should be optimized, additional time and cost were needed. Cloud computing can enable the relationship between the manufacturer and suppliers of aircraft, which is representative of mass customized products, to be flexible and efficient. In order to enhance the response time during contracting with suppliers, this paper focuses on an architecture, providing a service for a decision with the concerns about the time and cost as well as energy with regard to process planning. For realizing this service the manufacturer provides the process plan described using neutral language for numerical controllers called 'STEP-NC' which is independent from a specific machine tool. On the supplier side, the machinability check, tool path generation and energy use estimation should be identified with machine tool specifications described by STEP-NC. In the Cloud computing environment, the analysis is performed to check the possibility that a supplier can complete a new order from the manufacturer on the due date with the analysis of machine tools and on-going production schedule. This function is developed in a system which can be installed on a virtual platform and provided by a cloud service.

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Cloud manufacturing;Factory planning;Order planning;Manufacturing network;STEP-NC;Energy-efficient process;Last minute selection, Milling machine

1. Introduction

Aircraft are make-to-order products and consist of a huge number of parts. For this reasons, tremendous suppliers are involved in its production. If a new model or a new product in this industry is launched, the aircraft company has to find the some number of suppliers the parts. In order to reduce the time and cost of subcontracting between suppliers and the manufacturer an information network providing interoperability between the individuals for the subcontract is needed. This paper focuses on the problem of the subcontracting procedure.

Recently, many researchers proposed services exchanging manufacturing data for machining parts by developing Cloud computing. March emphasizes the flexibility of Cloud computing [1]. In addition, Wu shows an approach in which a machine tool is a resource that can be shared by many users via Cloud computing [2]. Wang proposed overall concept of Cloud computing architecture called 'Cloud manufacturing' and integrates STEP and STEP-NC which are the standards for process planning enabling realizing of seamless information exchange [3].

One of the main advantages of these services and architectures is that it is possible for 'last minute selection' improving the flexibility and usability of manufacturing

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resources such as machine tools. To maximize the benefit, the KPI (Key performance index) of each supplier should be evaluated. ISO 14649 enable checking the machinability and identification of the productivity for the level of process planning. Avram and Xirouchakis and Choi and Xirouchakis estimate the energy requirements during the use phase of the spindle and feed axis in a machine tool system by taking into account stead state and transient regimes [4, 5].

Proposed architectures have been developed for the purpose of exchanging data for STEP-NC files and KPIs. Thus, the development of the calculation modules and the architecture passing messages in a Cloud computing environment is necessary. This paper proposes an architecture enabling checking of the machinability, primitive tool paths, and estimation of the energy consumption in the level of subcontracting. The architecture serves the message passing in the real procedure of an aircraft company. Also PaaS (Platform as a Service) is utilized to program the application software of various user devices. On the serve side, HTML5 and Javascript, which is a message standard of Cloud computing, are used.

In this paper, section 2 illustrates the subcontracting procedure of an aircraft company. A Cloud computing architecture and the procedure of message passing are described in section 3. The algorithm for generating primitive tool paths and calculation method of KPIs on the supplier side are shown in section 5. The conclusion of this paper follows in section 6.

2. Order planning

General subcontracting is that prime contractor hires several sub-contractors to perform a specific project. In proposing case prime and suppliers are an aircraft manufacturer and part manufacturers, respectively. The overall process is illustrated in Figure 1 and consists of three main steps: 1) Prime pre-selects available candidates among suppliers, publishing the URLs in advance. Prime gives suppliers a requirement model of machine tools which are able to produce new part. The requirement model is automatically generated from a STEP-NC part program. 2) In the next step, KPIs of suppliers are calculated and prime compare suppliers. Part-program, geometric data, and bill of material will be downloaded from the prime's database. The prime sends all detail of process planning such as geometry and program. The data given by the prime has the neutral part program which is independent of specific machine tool and includes the range of machining condition. Best machining condition is calculated by the supplier. At the same time, the primitive tool paths are generated from the neutral part program. The process time, cost, and energy use are derived from the tool path data. They are KPIs reported to the prime. Prime sorts the KPIs of available suppliers with own priority in order to make a final decision about the supplier. 3) Lastly suppliers start to produce parts and continuously report the result of its production.

3. Proposed manufacturing network

3.1. Cloud computing architecture

Due to changes in the information system platform high cost has been required for current development of the network software connecting manufacturers and suppliers. PaaS is an important concept of Cloud computing which provides the computing platform and tools for creating the software [6]. It

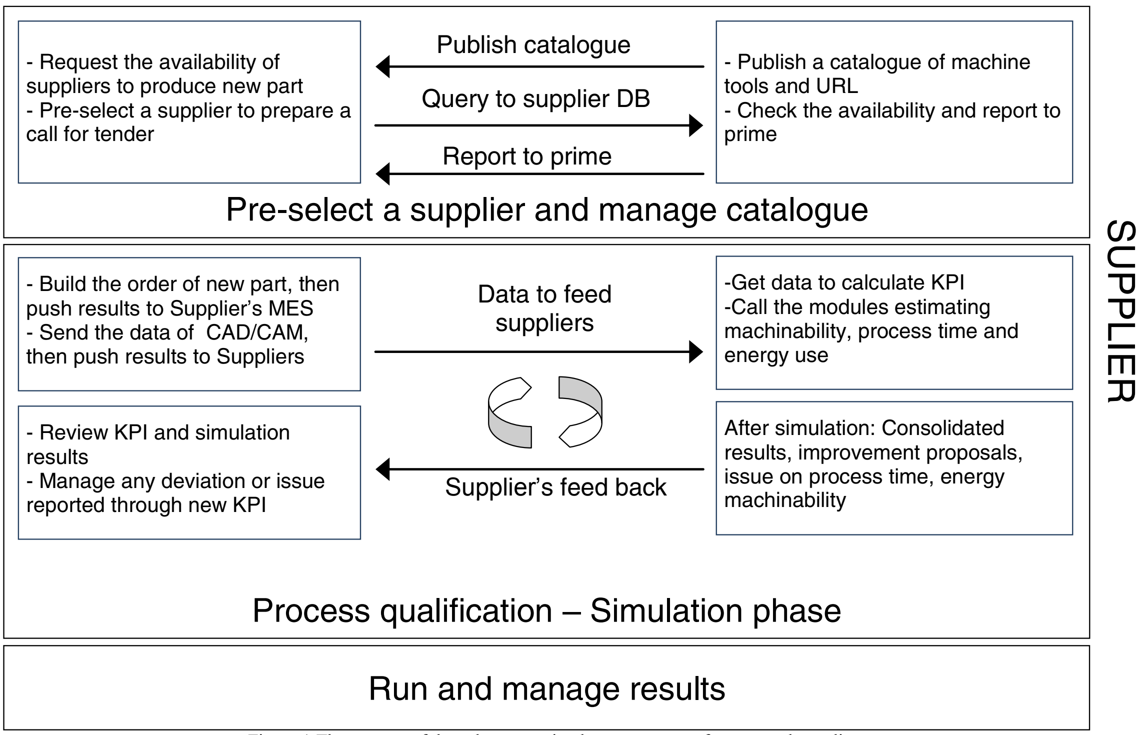

Figure 1.The process of the sub-contracting between a manufacturer and supplier

also helps a programmer reduces his/her effort of developing new software operating on various operating systems such as Android and iOS. The proposed scenario was realized by network software developed by PaaS as shown in Figure 2.

In the development step, fundamentally using single standard language on the server side and client side reduces the difficulties for software development. The codes for message passing or file transfer are the same on the two sides. In this research the developer tools utilizing Javascript and HTML5 were used. On the client side, PhoneGap is the PaaS for developing Apps for various smart phones with single code described with Javascript and HTML5 and creates a user interface software operating on Android, iOS, and Windows 8 [7]. The PhoneGap code itself can be read by general web browsers. There are various operating environments of users. The user interface apps are installed on a user's computer, tablet PC, or mobile phone.

For the manufacturer, the main issue of manufacturing step is the method for message passing. Subcontracting with suppliers is not a frequent task when a new product is planned. Thus, an event-driven server connecting whenever the supplier is needed is suitable rather than a high-performance server based on multi-threading which is used for large data processing such as data mining. About the connection type, it is enough for RESTful message consisting of GET, POST, PUT, PATCH, and DELETE operations defined in HTTP protocols [8]. This type can make looser coupling than WebService. With these simple operations, the connection with suppliers is simple and easy to develop. To subcontract with a supplier the manufacturer users install the user interface app and download the URLs of suppliers. Then whenever a new supplier is needed, the user interface app generates an event and sends a message.

For suppliers, it is installed on the server computer for Node.js which is an event-driven server based on Javascript [9]. Node.js allows conductors to move components seamlessly between mobiles. With this approach, all components are written in Javascript such that the same component can be run in a hosted environment in the cloud, or on mobile devices. This server is very light and fast and provides access inside the computer device. This access is a different feature from common Javascript which cannot execute the local files and connect directly device or sensors. Node.js gives the linking with 3 modules for checking machinability, generating tool path, and evaluating energy use.

3.2. Message passing and data model

This section describes the details of messages and data models transferred in the proposed architecture. Basically the intelligent language of the part program is required in order to establish the negotiation function mentioned above. In this research STEP-NC is utilized for this purpose. The details of STEP-NC are discussed by Suh et al. [10].

The process for message passing follows the given scenario of sub-contracting. On the supplier selection level, URLs on the supplier's server are published and downloaded by the manufacturer. The requirement model generated with the STEP-NC part program is transferred to suppliers. The requirement model is a part of the machine tool model described in ISO 14649-201 [11] and a standard about the characteristics of machine tools required for producing a product defined in a STEP-NC file. The characteristics include spindle power, size of the workspace, and types of operation. With this requirement model, the supplier reports the machinability of the product. The manufacturer determines the candidates with the reports received and sends order messages to selected suppliers.

On the simulation level, the supplier sends the agreement message as a response to the order message. A STEP-NC part program is transferred to a supplier for the purpose of evaluating KPIs required for final decision of the manufacturer. STEP-NC is a neutral language for machine tools. This is the representation with Workingsteps which is a conceptual unit of machining such as pocketing and contouring. Workingsteps include removal volumes, machining conditions, and strategies. It is an indirect way to represent the tool path without a series of points along specific coordinate systems given by a controller. With the help of this conceptual approach, each controller generates tool paths by

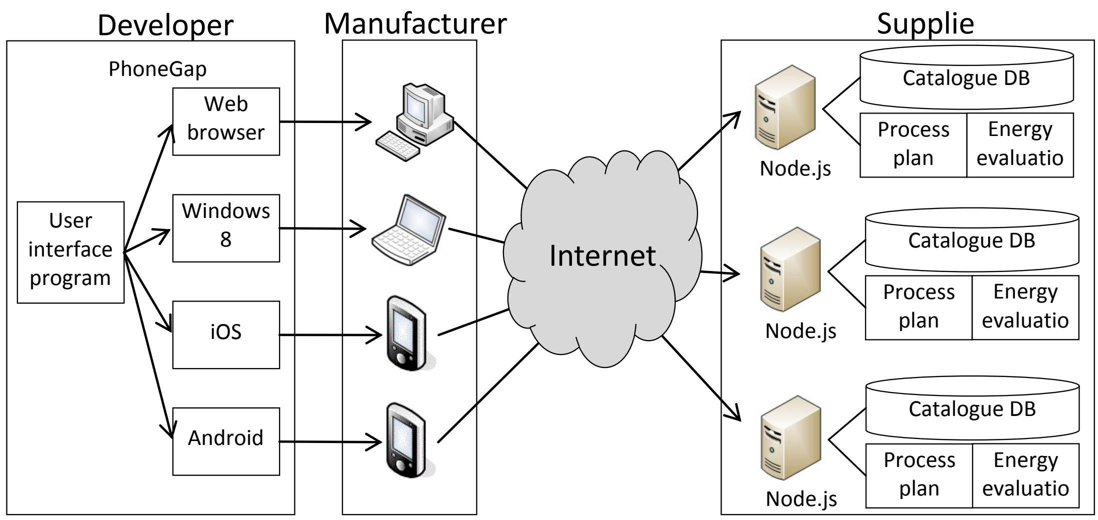

Figure 2.Cloud computing architecture of the sub-contract network

itself. The next step is reporting KPIs. A KPI is calculated by calculation modules called by the Node.js server. A KPI is composed of the allocated machine tool, process time, and energy use.

4. Algorithm for primitive tool path and calculation method of KPIs

4.1. Process planning

This algorithm has the aspects of identifying the machinability and of defining multiple process plans. Currently many manual inputs of catalogue data distributed machine tool builders are required. Standardization of the machine tool data reduces manual tasks and provides a way for the system to understand the details of specific machine tools. The procedure of this algorithm is: 1) to read the requirement model generated from the part program and the catalogue model of a target machine tool, 2) to compare the data with a catalogue model with the rule, and 3) to sort the machine tools with necessary functions in according to the priority given by the process planner. The rule is related to the machine capability, work space, and tolerance of the specification of each machine tool. With the result of machinability checks, the supplier allocates a machine tool.

For available machine tools of each supplier, tool paths are generated. As mentioned above, the conceptual data about tool paths is provided from a STEP-NC part program. The procedure for tool path generation consists of reading a STEP-NC file, offsetting paths, and linking the paths. A physical file of STEP-NC using ISO 10303-21 is described by a set of lines of entities defined in ISO 14649. In order to find data related to each Workingstep, examining all lines is necessary. After all data of a Workingstep are found, offsetting is carried out with the information of removal volume and machining condition. Offset paths are linked using strategies. Retract/approach and rapid movement are added to starting points and end points.

4.2. Machining Energy Estimation and Production planning

First of all, multiple process plans should be defined in terms of each supplier (i.e., each factory) on the basis of STEP-NC supported from a manufacture. The multiple process plans, an extension of a single process plan, specify alternative operations and alternative machines [12]. Due to the different status (i.e., system configuration and customer demands) of each supplier, multiple process plans defined and energy consumption required are different. In addition, results from the production planning are different. Through those activities, we can get the possibility that a supplier can complete a new order and also estimate total machining energy consumption required to complete the order.

4.2.1. Machining Energy Estimation

Depending on various variables influencing the actual machining energy consumption such as the type of manufacturing process, process parameters and the structure/components of the specific machine tool, the energy requirement is estimated with respect to multiple process plans defined from each supplier. The energy consumed by various activities from all power driven resources involved during the machining of one part is categorized as part machining energy in the study. The energy for the part machining is determined by the energy estimation model suggested by Choi and Xirouchakis [5]. The processing system consists of machine tools provided with a local tool exchange and tool storage systems, internal chip conveyors and cutting fluid recirculation systems. The part machining energy can be estimated on the basis of different usage modes of the machine tool and their respective time share in the covered time span (idle, setup, runtime and cutting). The part machining energy E_{ij}^{PM} (kJ) consumed according to process plan j related to part i can be estimated by multiplying the powers required and operation times for operations related to the process plan.

The idle energy is estimated on the idle power (P_{idle}) drawn constantly as long as the machine is on which is a machine-specific value and their operation times. If the pallet uses a hydraulic pump in order to clamp the parts during the setup mode, its pallet change power requirements (P_{pc}) should be accounted for as part of the setup activities. The energy is estimated on the basis of pallet exchange time (t_{pallet}), the idle power, the pallet change power and the number of parts mounted on a pallet.

The runtime mode addresses all the activities performed by the machine tool over the length of the part program in order to support the material removal. The following activities fall under this category: steady-state running of the spindle and feed axes, the tool changes, cutting fluid pumping and removal of the chips from the machine tool area. The steady-state energy is estimated by the steady state power ($P_{stead-stage}$) required by an operation and their operation time. For complex part programs requiring many tool changes, the tool change energy is estimated on the tool change power (P_{tc}), idle power, tool change time (t_{tc}) and number of tool change in a process plan. In addition, mechanical chip removal conveyors are built into the machine to discharge continuously the chips produced during machining. The screw conveyors are usually employed for the evacuation of the chips outside of the machine. The energy related to screw conveyor systems is estimated on the screw conveyor power (P_{screw}) and the operation times. The energy for cutting fluid delivery responsible for the delivery of the cutting fluid to the cutting area of each machine is estimated on the cutting fluid delivery power ($P_{pump}^{delivery}$) and the operation times. On the machine side, there is only one pump that will transfer the fluid from the tank of the machine back to the centralized system. Therefore, the energy estimated on the power (P_{pump}^{return}) and the time (t_{teturn}) required by the return pump should be considered in the part machining energy. In the cutting mode, the energy for a cutting power (P_{cut}) is estimated on the basis of cutting force, cutting speed and the operation times.

4.2.2. Production planning

From each supplier, the following production planning model will be applied. In the production planning model examined in this study, we assume that a company produces N types of products to satisfy customer demands over planning horizon T. Each product type has multiple process plans which are defined on the basis of alternative operations and alternative machine tools defined by each supplier. The production planning model is developed as a linear programming with an objective function for minimizing the weighted value the energy consumption and inventory holding cost, subject to linear constraints pertaining to a resource (i.e., machine tool) and the customer demands. Each of the suppliers is made up of different machine tools. Based on those data, the capacity for the selected resources is estimated in the production planning model.

Before determining the production planning problem, the process planning should be performed. The major work of process planning is to specify technological instructions describing how to make a product. In addition, the machinability of the pallet on possible machine tools should be already verified in each supplier through the process planning approach [13]. Through the suggested planning model, we get two important KPIs in the study. The first is to check the possibility that a supplier complete a new order with due-date from the manufacture. The second is to estimate also total energy consumption required to complete the order on the basis of energy consumption from the selected process plans.

5. Concluding remarks and Future works

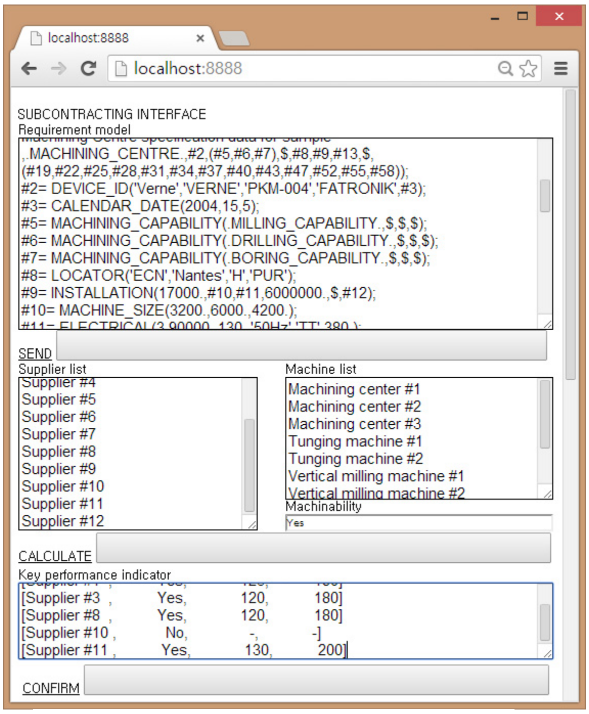

Figure 3. Screenshot of user interface for manufacturer

The proposed architecture consists of a user interface developed through the development tools according to proposed message passing, the calculation modules of KPIs, and the Node.js server. All messages follow web standards of HTML5 and Javascript because the STEP-NC physical file is described in text format. On the server side, the calculation module of the process plan is implemented in MATLAB. The Energy estimation module and production planning is programmed in C++. Node.js provides the direct access to the local execution file while normal Javasc ript does not allow managing a local file. The current scope is a single machine and product produced by a milling machine. The user interface of manufacture and the calculation modules were developed as shown in Figure 3. Also, the procedure for multi-suppliers is defined. Future work, On-going plan is to extend the range of the message to multi machine and products of turning parts and 3D printing shapes.

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